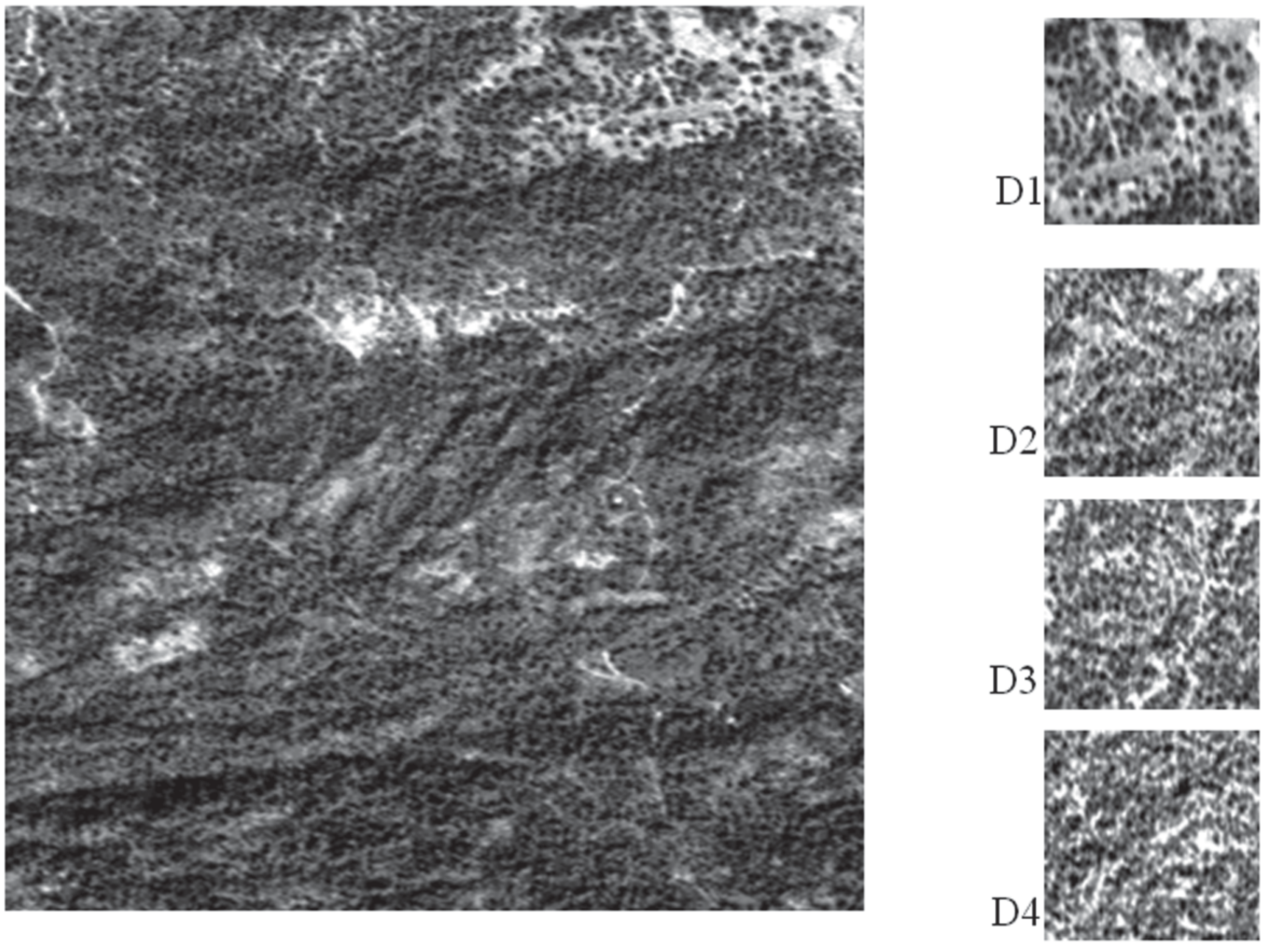


Figure 3.5: IRS Pan data for forest crown density mapping

Chandrashekhar *et al.*, 2005 demonstrated the test-assessment and practicability of forest canopy density mapping using satellite remote sensing data and biophysical spectral response modelling. Forest canopy density stratification through object oriented image analysis and conventional method of visual interpretation also have been compared with the Forest Canopy Density (FCD) Mapper semi expert system. In this study, forest canopy density was effectively stratified through linear multi-parametric approach by utilizing advanced vegetation index, bare soil index, shadow index and thermal index. Isodata cluster analysis of forest canopy density map derived from FCD Mapper and conventional methods were shown similar results with respect to percent area of forest and non-forest. The high percentage (10-30%) occurrence of bushy vegetation like *Lantana Camera* in ground canopy poses challenge in delineation of forest canopy density as its spectral reflectance is similar to that of the forest. Similarly, Roy *et al.*, 1996 conducted a study in which a three way crown density model was developed for the classification of forest crown density classes which utilizes the vegetation index, bare soil index and canopy shadow index.

3.3.3.4. Forest Quantification - Inventory Approaches

The precise estimation of forest ecosystem parameters depends on the efficiency of three stages of quantification process viz. design stage, estimation stage and inference stage. The design stage means selecting the design by which the data is gathered, the estimating stage selecting and using the estimators for the parameters of interest i.e., population means and totals, and the inference stage analyses the accuracy of these estimators i.e. calculation of standard errors and confidence levels. Geoinformatics based approaches involving remote sensing, GIS, GPS and information science enhances the development of reliable, time and cost effective approaches. In forested ecosystems selected features are typically identified by their location. Consequently, any quantitative assessment needs spatial perspective: sampling in space. There are two scientifically robust approaches for sampling and extrapolating from a sample to an entire population i.e. design and model based methods. The principle difference between the design and model-based approaches lies in the source of randomness they utilize. Both these approaches are effectively used in the development of different quantitative database on growing stock, biomass and species diversity in the country.

3.3.3.5. Forest Quantification – Biomass, LAI from NDVI

One of the important ways of enhancing the efficiency of estimation is to bring out reliable stratification of the complex population and optimally sample subpopulations. The satellite remote sensing provides precise stratification in terms of forest crown density, vegetation types, communities and species formations which can form the basis for reducing the strata variance and make precise estimates. This assumes larger relevance in the context of high degree of variability of spatial distribution of vegetation types in India. The spatial explicitness in the estimates was brought out at desired scale and accuracy through geostatistical tools and GIS based spatial balancing methods. However, the resolution of spatial explicitness depends on the details of stratification and intensity of ground sampling required for scale and type of assessments.

Broad leaf tropical forests exhibit unique structural and environmental responses in the spectral domain. The increase in biomass levels results in the increase of reflectance values. NDVI, LAI and biomass are significantly correlated with ground estimated biophysical parameters. The regression models developed as part of several studies can also help in generating spatial biomass map. The attempt made in this direction showed strong possibility of using spectral response-based models for biomass estimation. However it is noteworthy that remote sensing-based Above Ground Biomass (AGB) estimation is a complex procedure in which many factors such as atmospheric conditions, mixed pixels, data saturation, complex biophysical environments, insufficient sample data, extracted remote sensing variables, and the selected algorithms, may interactively affect AGB estimation. The increase in reflectance of the NIR provides a remarkable capability for distinguishing vegetation from almost any other surface material, especially soil and water. Thus, this contrast is the basis for the application of vegetation indices in the estimation of vegetation parameters.

Studies have established relationships between the LAI of the canopy and vegetation indices from the signal reflected from the top of the canopy in the NIR and Red regions of the spectrum. The IRS LISS-IV data could be successfully used for forest patch level estimation with better accuracy.

3.4. Review of Literature

3.4.1. Coarse-resolution remote sensing

Over the past few years, global datasets from coarse spatial resolution sensors have become more and more readily available (e.g. Townsend *et al.* 1994, Arino & Melinotte 1995). Use of satellite image data for mapping and monitoring (Table 3.6) global land-cover, biomass burning, estimating geophysical and biophysical characteristics of terrain features, or monitoring continental-scale climate shift, is a primary input for biodiversity assessment. The rapid revisit time of AVHRR helps better understanding of land cover, burnt area, etc., at both global and regional levels (Stone *et al.*1994, Loveland & Belward 1997, Eva & Lambin 1998). The global vegetation type maps, analyses of land-cover changes and burnt areas in conjunction with trends in human disturbance, are effectively used to generate coarse-scale biodiversity maps and identification of biodiversity hotspots. In addition, the Moderate Resolution Imaging Spectroradiometer (MODIS) is designed to provide consistent spatial and temporal comparisons of global vegetation conditions that can be used to monitor photosynthetic activity, which facilitate understanding the biodiversity function.

During broad-scale mapping of Western Ghats (1:1,000,000 scale), 205 patches belonging to 11 different landscape types consisting of topography, climate, population, agriculture and vegetation cover, were delineated using IRS 1B data (Nagendra & Gadgil, 1998). In a detailed analysis in the tropical forests of the Western Ghats of India, Nagendra & Gadgil (1999) mapped a landscape into seven habitat types ranging from secondary evergreen forests to paddy fields, using supervised and unsupervised classification of IRS-1B LISS-II satellite imagery. The nature and the extent of forest degradation and its causes have been intensely debated, using mesoscale analyses of forest condition in the region of Western Ghats (Lele *et al.,* 1998).

Table 3.6: Satellite Remote Sensing sensors and potential in biodiversity assessment (Murthy *et al.*, 2003)

Scale	Data sources	Forest attributes	Spatial resolution	Temporal frequency	Mapping scale	Monitoring cost
Global	NOAA-AVHRR MODIS WIFS	Phenology types Forest / Non Forest Net Primary Productivity Deforestation Biomass burning	180 - 1 Km^2	Daily	>1:5000,000	Low
Regional	IRS LISS	Forest / Habitat types Secondary types	5 - 90 m	5 - 25 days	>1:50,000	Low to high
	IRS PAN	Disturbance - logging/roads/fire /encoarchments Plantations Ecotones				
	Landsat Spot	Wetlands Gregarious formations				
	JERS-1	Target species with gregarious distribution				
	ASTER					
Local	IKONOS	Target species with gregarious distribution	< 5 m	User defined	>1:10,000	High
	Aerial photography	Species assemblages / Communities				
	Aerial multispectral scanner	Regeneration				
	LIDAR CASI	Forest disturbance Agriculture Logging / roads Canopy gaps Plantations Harvest rates Level of degradation				

3.4.2. High-resolution remote sensing

Rapid change in land-use in tropical areas and the need to map changes in land use over large areas effectively, calls for application of high- or very-high-resolution satellite sensors. At the national or local level, IRS, Landsat or SPOT imagery can provide finer-scale information on forest type distribution and agricultural expansion. Radar systems, such as JERS and Radarsat, are not affected by clouds, and are useful for determining the extent of forest and non-forest landscapes where topographic relief is not substantial (<200m). Vegetation type and land-cover mapping of the entire North-East India, Western Himalayas and Western Ghats of India, were mapped on a 1:250,000 scale by using IRS LISS data (IIRS, 2002). Tropical evergreen forest along with other phenological types and major disturbed habitats (grassland, orchards, mangroves, Myristica swamps and Ochlandra) were mapped. The spatial data generated by remote sensing is useful in many ways in biodiversity monitoring and conservation efforts. Datasets from IRS 1C/1D LISS-III have been used effectively in mapping the pure plant colonies of *Hippophae rhamnoides* in the Spiti region of India with prior knowledge of their occurrence and vegetation types of the area by using remote sensing (Roy *et al.* 2001). IRS 1C/1D LISS-III FCC has been used for stratification of *Ephedra gerardiana* in complex terrain conditions of Lahul and Spiti district (Porwal *et al.,* 2003).

In areas where vegetation structure varies greatly, structural rather than species differences may predominate in imagery. These methods may then prove less suitable for determining species composition and facilitate delineation of specific vegetation types and habitats. In 1995, White *et al.* used LANDSAT TM imagery for an unsupervised classification of the forest of the Lassen Volcanic National Park. Genus-level mapping into Pinus and Abies forest classes was achieved with an accuracy of 63%. Treitz *et al.,* (1992) carried out a study in the Presquile Provincial Park, Canada. MEIS-II data, with five bands of 3 nm, was related to species-based community classification. Franklin (1994) carried out an analysis using satellite imagery to differentiate compositionally distinct vegetation communities. LANDSAT TM was used for estimation of species richness, indicating biodiversity hotspots in riparian and ecotonal areas (Gould 2000).

Remote sensing based on habitats, in conjunction with information on species habitat associations, can be generally used to derive information on the distribution of species, although a few exceptions may exist (e.g., Treitz *et al.* 1992). The degree of correspondence between habitat and species distributions depends on the degree of habitat map generalization, and this should also be optimized to get maximum information on species diversity (Stoms 1992, Coops & Catling, 1997). Habitat appears capable of providing information on the distribution of large numbers of species in a wide variety of areas. However, this is restricted to the spatial scale of tens of square kilometers. In smaller, local areas with limited species diversity, direct mapping can provide detailed information on the distribution of certain canopy tree species or associations.

3.4.3. Very-high-resolution remote sensing

Applications of very-high-resolution remote sensing techniques to the conservation of biodiversity, assessment of protected areas, and species protection, show that fine-grain remote sensing is underused in conservation of forest ecosystems. Very high-resolution data (1m panchromatic and 4 m multispectral), which are now available from the commercial IKONOS II satellite, may be useful for determining the actual activities on the ground that have led to forest clearing. Although such data can detect very small clearings, the scientific community as yet has very little experience with these data. In addition, laser scanner data in combination with very-high-resolution satellite images, e.g. IKONOS, Terra Aster platform, or aerial multispectral scanner data, can be applied to the assessment of heights of single trees, tree-wise timber volume calculations, and the detection of even single trees of other species, especially for forest inventory tasks. The synergy of these different data sources can guarantee foresters a high level of information extraction for these applications.

Mapping of diversity estimates is often accomplished by analyzing the variation in spectral signal, and correlating this variation with measures of landscape or taxonomic diversity (Rey-Benayas & Pope 1995, Jorgensen & Nohr 1996). Mapping individual trees by using high-resolution data, poses problems not encountered when mapping associations or habitat patches. Pixels covering different component of a tree, such as bark and leaf, can be extremely variable in intensities. This makes the spectral signature of a tree species difficult to define. The factors like crown closure, crown geometry, stand density, topography, soil type, etc., regulate the reflectance properties of vegetated surfaces, so characterization of individual species, communities and vegetation types is a complex process. However, few studies have reported on the use of hyperspectral image data for differentiation of several tropical species (Franklin, 1994, Martin *et al.*, 1998) as well as discrimination of coniferous species (Cochrane, 2000, Gong *et al.*, 2001). Researchers in the Yellowstone National Park used Landsat and a Geographic Information System (GIS) to categorize habitats a priori and then determined the relationship between remotely sensed habitat categories and species distribution patterns (Debinski & Humphrey 1997, Debinski *et al.* 1999, Van Horssen *et al.*, 1999).

3.4.4. Temporal monitoring

The amount of change that is occurring in tropical parts of the World has been of considerable interest in the past ten years. Remote sensing offers perhaps the only practical method of analyzing large areas over time. Green & Sussmann (1990) used a combination of aerial photography, forest maps, and satellite images to estimate deforestation rates in Madagascar from 1950 to 1985, spanning a total of 35 years. With the advent of availability of satellite remote-sensing data, several countries have recently launched temporal monitoring of forest cover, which facilitates analyzing biodiversity losses. However, these studies do not provide information on vegetation type transition and losses, which is primarily necessary for understanding shifts and losses in biodiversity.

A few examples of the studies conducted in southern Western Ghats of India and Vindhyans of central India and North-East India have provided details about vegetation type transitions. These transitions, when coupled with ground-based species databases, help in analyzing and quantifying biodiversity losses. Prediction of the spatial distribution and relative abundance of wildlife on the basis of multitemporal satellite data and simulation models is also a recent development; Coops & Catling (2002) extensively reviewed such approaches.

3.4.5. Hyperspectral remote Sensing

Hyperspectral remote sensing is a relatively new technology. It is currently being investigated by researchers and scientists with regard to the detection and identification of minerals, terrestrial vegetation, and man-made materials and backgrounds. The ability of imaging sensor to acquire the reflectance spectrum of pixel in significant detail leads to substantial difference in the reflectance values of pixel belonging to disparate material of earth surface. Actual detection of materials is dependent on the spectral coverage, spectral resolution, and signal-to-noise ratio of the spectrometer, the abundance of the material and the strength of absorption features for that material in the wavelength region measured. There are many applications which can take advantage of hyperspectral remote sensing.

- Atmosphere: water vapor, cloud properties, aerosols
- Ecology: chlorophyll, leaf water, cellulose, pigments, lignin
- Earth Science: mineral and soil types
- Coastal Waters: chlorophyll, phytoplankton, dissolved organic materials, suspended sediments
- Snow/Ice: snow cover fraction, grainsize, melting
- Biomass Burning: subpixel temperatures, smoke
- Commercial: mineral exploration, agriculture and forest production

Current and recent important Hyperspectral Sensor and Data providers include spaceborne Hyperion onboard EO-1 providing data from 220 spectral bands and airborne sensors such as AVIRS with 224 bands, Hydice with 210 bands are operating in 0.4-2.5 µm. Hymap and DAIS 21115 are working in visible and thermal IR regions is providing data in 200 and 210 bands, respectively. Based on the international and domestic experience the following hyperspectral sensor configuration will be of immense use in the Indian space programme. Hyperspectral sensors are able to discriminate, identify and determine many characteristics about earth's features. Hyperspectral image analysis requires more attention to issues of atmospheric correction and relies more on physical and biophysical models than statistical techniques. Physical modeling and Empirical modeling are the approaches that can be employed to relate digital remote sensing data to biophysical variables.

3.4.6. Microwave and LIDAR sensing of forests

Recent advances in instrumentation and techniques are producing estimates of biomass with unprecedented accuracies in even the most densely forested ecosystems. Traditionally, these attributes have been measured in the field using handheld equipment. Field methods are accurate but are time-consuming and therefore limited to either mapping at fine scales or relatively sparse sampling at the landscape scale. Multi-spectral and hyper-spectral remote sensing have been used to map some aspects of structure at moderate resolution and broad scales. However, passive optical sensors have difficulty penetrating beyond upper forest layers and are better suited for mapping horizontal components, such as land cover type. Synthetic aperture radar (SAR) and interferometric synthetic aperture radars (InSARs) can provide measures of vertical structure at landscape scales at varying degrees of accuracy. Scientists used a ratio of P- and C-bands and the HV polarization (PHV/CHV) as well as L to C ratios (LHV/CHV) to predict biomass in boreal forests. Researchers found a direct correlation between biomass and X and L-band with HV polarization (LHV/CHV) backscatter, again in a boreal forest. Many other studies reported accurate results for biomass retrieval are in plantations or in very simple (in terms of either physiognomy or floristics or both) forest types. SAR and InSAR appear to be suited for structurally homogeneous, simple forest types at the present time, although advances in technology should improve estimates in other ecosystem types.

Light detecting and ranging (LiDAR) provides highly accurate measurements of forest structure. Due to the high cost of flight time, the need to limit scanning to near nadir in order to prevent ranging errors, and the presence of coverage gaps due to aircraft pitch and roll, many LiDAR studies provide samples at the stand level or image small areas, most missions do not provide the same wall-to-wall coverage at the same scale as a Landsat TM scene or SAR image. In India, this technique could be utilized to address various aspects of forest ecosystem management, not possible earlier with the data available from aerial photographs, optical and radar satellites or even by ground measurements (Behera and Roy, 2002).

The optimal strategy for mapping forest structure would include the finely-detailed measurements of the vertical dimension that currently only field sampling provides as well as the broad spatial coverage and lower cost per unit area provided by remote sensing. Although no single technology is capable of providing this level of forest structural information at the present time, improvements in Radio Detecting and Ranging (RaDAR) and Light Detecting and Ranging (LiDAR) will likely lead to broad-scale mapping of vertical structure in the near future.

Direct measurements of forest structure that are highly correlated with biomass include diameter at breast height (dbh), basal area, canopy height, and crown volume. RaDAR and LiDAR systems make measurements of some of these variables directly, e.g., canopy height, and/or make measurements which can be used to infer these variables. Numerous researchers, have shown that these different LiDAR or RaDAR measurements, considered separately, can be used to estimate forest biomass. It has been demonstrated through experiments that if these different LiDAR and RaDAR forest canopy measurements, considered jointly, produce more accurate, precise estimates of above ground forest biomass. It can also be determined which of the LiDAR height and RaDAR height and cross-sectional returns most accurately predict total above ground forest biomass in arid, relatively heterogeneous ponderosa pine stands.

3.4.7. Geomatics and Forestry

Geoinformatics (geographic information science, geomatics) aims at the development and application of methods for solving specific problems - with special emphasis on the geographical position of objects.

The future research direction and opportunities will be significantly affected both by the availability and utilization of Information Technology. As the complexities of processes are only recently being recognized through the application of new technologies, it is evident that an enormous gain in understanding can be realized only if multidisciplinary data are evaluated numerically, and integrated geospatially through the utilization of Information Technology. Ever-growing understanding and acceptance that the Earth functions as a complex system composed of myriad interrelated mechanisms have made scientists realize that existing information systems and techniques used are inadequate. Currently, the uncoordinated distribution of available data sets, a lack of documentation about them, and the lack of easy-to-use access tools and computer codes are major obstacles for scientists and educators alike. These obstacles have hindered scientists and educators in the access and full use of available data and information, and hence have limited scientific productivity and the quality of education. Recent technological advances, however, provide practical means to overcome such problems. Advances in computer design, software, disk storage systems as well as the growth of the World Wide Web (www) now permit for the first time the management of gigabytes to terabytes of data for distribution to scientists, educators, students, and the general public.

Remote Sensing and GIS are disciplines that are strongly data driven, and researchers and government agencies often develop large data basis. The complexity of the fundamental scientific questions being addressed requires integrative and innovative approaches employing these data basis if we are to find solutions. Although a number of databases exist, the ultimate goal is to create a fully integrated data system populated with high quality, freely available data, as well as, a robust set of software to analyze and interpret the data. This system would feature rich and comprehensive databases and convenient access. These capabilities are needed to attack a variety of basic and applied Earth Science problems.

The present day problems are inherently four-dimensional (x,y,z,t) in nature involving variation with time. Thus, their solution requires data analysis that is far more complex than provided by traditional Geographic Information Systems (GIS). The extent, complexity, and sometimes primitive form of existing data sets and data bases, as well as the need for the optimization of the collection of new data, dictate that only a large, cooperative, well -coordinated, and sustained effort will allow the community to attain its scientific goals. With a strong emphasis on ease of access and use, the resulting data system would be a very powerful scientific tool to reveal new relationships in space and time, and would be an important resource for students, teachers, the public at large, governmental agencies and industry. Fundamental new discoveries will require the availability of databases that encompass a variety of temporal and spatial scales. Because of the need to integrate heterogeneous data sets and tools to analyze them, Geoinformatics provides the focus for community participation in a national experiment to enhance and retain the pre-eminent role in the world.

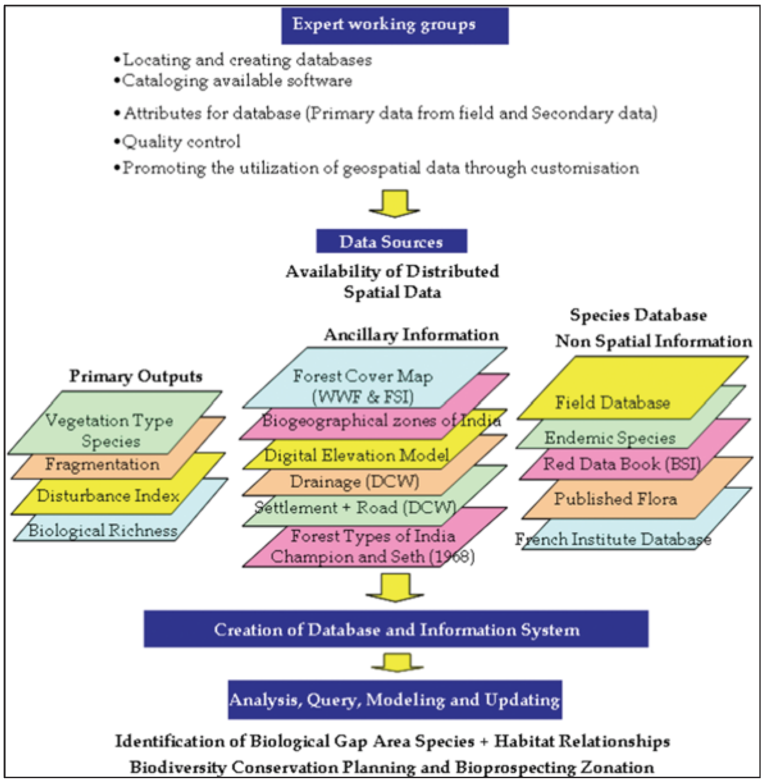
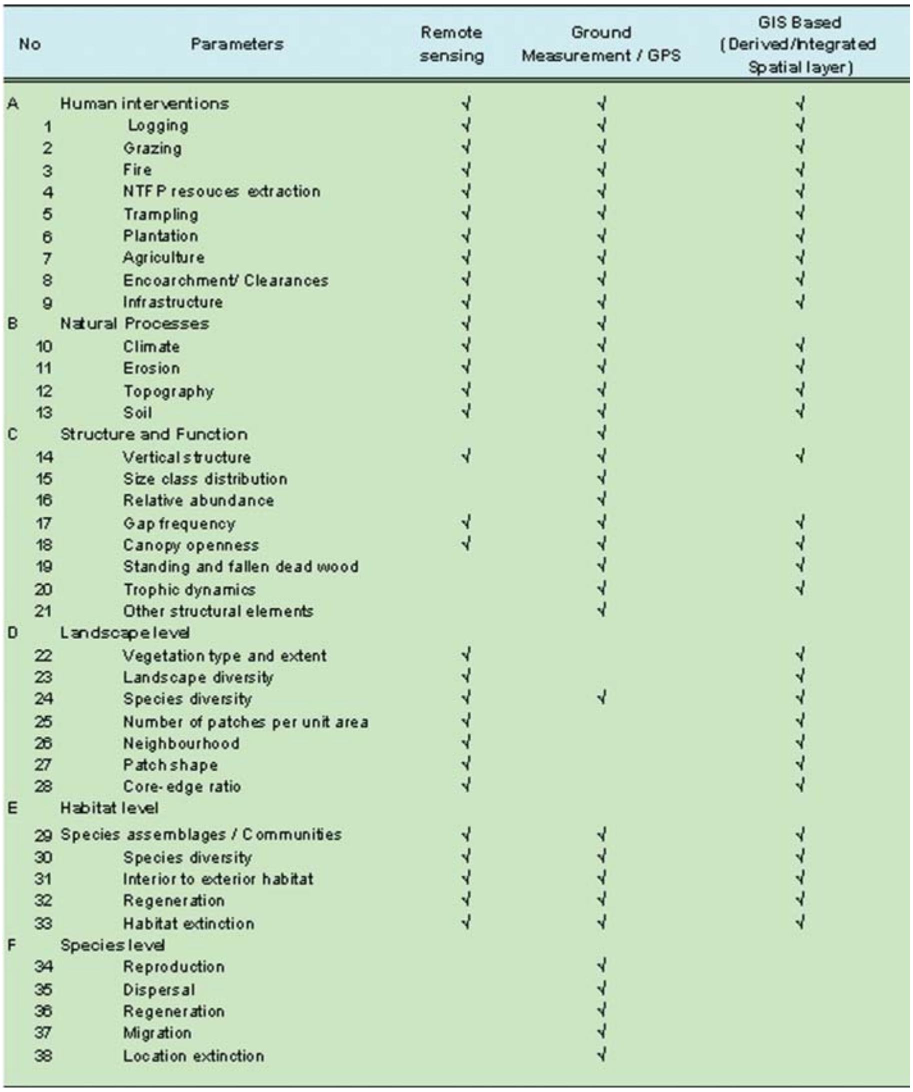


Figure 3.6: Steps in geoinformatics for creating biodiversity information system

The environmental control on the forest vegetation is well documented (Mueller-Dombois, Dieter and Ellenberg 1974). Physiography, topography, climate and human interventions largely control the distribution of vegetation and biodiversity. The developments in computer based Geographic Information System (GIS) enables the integration of spatial and non-spatial information for defining the habitats and improving vegetation type descriptions in space and time. A review on GIS and database for vegetation mapping and monitoring is given by Skole *et al.*, 1993. It is also possible to evolve geospatial models using multi criterion to present disturbance regimes and landscape diversity. Landscape ecology has evolved as an operational tool with the availability of geospatial modeling techniques. Tomlin (1990), Mc Guire *et al.*, 1988, Antencci *et al.* (1991) and Miller (1994) provide number of examples of application relevant to biodiversity. The power of having all information and knowledge along with access, modeling, and visualization tools at the finger tips of a user has great potential in advancing science, accelerating the discovery process, and enhancing the quality of science and education. The steps in Geoinformatics for creating Biodiversity Information System are given Figure 3.6.

Table 3.7: Components of biodiversity assessment and measurement tools (Murthy *et al.*, 2003)



No	Parameters	Remote sensing	Ground Measurement / GPS	GIS Based (Derived/Integrated Spatial layer)
A	Human interventions	√	√	√
1	Logging	√	√	√
2	Grazing	√	√	√
3	Fire	√	√	√
4	NTFP resouces extraction	√	√	√
5	Trampling	√	√	√
6	Plantation	√	√	√
7	Agriculture	√	√	√
8	Encoarchment/ Clearances	√	√	√
9	Infrastructure	√	√	√
B	Natural Processes	√	√	
10	Climate	√	√	√
11	Erosion	√	√	√
12	Topography	√	√	√
13	Soil	√	√	√
C	Structure and Function		√	
14	Vertical structure	√	√	√
15	Size class distribution		√	
16	Relative abundance		√	
17	Gap frequency	√	√	√
18	Canopy openness	√	√	√
19	Standing and fallen dead wood		√	√
20	Trophic dynamics		√	√
21	Other structural elements		√	
D	Landscape level			
22	Vegetation type and extent	√		√
23	Landscape diversity	√		√
24	Species diversity	√	√	√
25	Number of patches per unit area	√		√
26	Neighbourhood	√		√
27	Patch shape	√		√
28	Core-edge ratio	√		√
E	Habitat level			
29	Species assemblages / Communities	√	√	√
30	Species diversity	√	√	√
31	Interior to exterior habitat	√	√	√
32	Regeneration	√	√	√
33	Habitat extinction	√	√	√
F	Species level			
34	Reproduction		√	
35	Dispersal		√	
36	Regeneration		√	
37	Migration		√	
38	Location extinction		√	

The holistic understanding of the complex mechanisms that control biodiversity, as well as their spatial and temporal dynamics, requires synergetic adoption of measurement approaches, sampling designs and technologies. The data requirements include data of both spatial and non-spatial nature and also of various time scales. In view of this, the combination of satellite remote sensing, Global Positioning System (GPS), and integrative tools (such as GIS and information systems) is an important complimentary system to ground-based studies. It has been well explained by Murthy *et al.* 2003 that these technologies together form the basis for geoinformatics. The various parameters required for biodiversity assessment and their amenability for measurements by different techniques is given in Table 3.7.

3.5. Major Application Projects

3.5.1. Different IRS satellite sensors and use for bioresources assessment

IRS P6 satellite provides unique opportunity of having different resolution sensors on the same platform. AWiFS (56 m), LiSS III (23.5 m), LiSS IV (5.6 m) provide the capability to study and assess different forest parameters at various spatial scales. Cartosat I data with 2.5 m resolution help in detailed assessment of forest structure and species composition. A large range and scale of information can be acquired by making use of all these sensors. Coarse resolution sensors with high repetivity as the AWiFS are being used effectively for monitoring forest fires, rapid forest cover monitoring, vegetation phenology, carbon sequestration and forest productivity studies at global and regional scale. LiSS III sensor having spatial resolution of 23.5 m has wide application for studying forest composition, gregarious formations, monitoring of forest stands and plantation activities. High resolution LiSS IV and Cartosat sensors have applicability in studies pertaining to canopy density, canopy height and mapping of individual trees of economic importance as Teak and Sal and NTFP (Non Timber Forest product) such as canes, gums, resins, fibre yielding forest species. Satellite remote sensing capabilities have undergone significant advancement over the years. Starting from coarse resolution MSS sensors of 1970's a range of sensors as the Cartosat, LiSS IV, LiSS III, AWiFS are available now which can be applied for sensing and monitoring various forest parameters. Similarly from simple mappings carried out with the earlier sensors in 1980's forest remote sensing has come a long way passing through the whole gamut of applications as monitoring and change assessments, biodiversity studies, fire detection and species prediction. Now the focus lies on developing Information systems and model ecological processes.

3.5.2. Forest Cover Assessment

At the backdrop of increased developmental activities, demand for land and forest as bioresource, the Government of India has taken up the task of assessing forest cover in 1986, National forest cover mapping was initiated by NRSA for the periods 1972-75 & 1981-83 using Landsat MSS data at 1:1 million scale. Forest cover mapping provides total forest area information in terms of crown density classes, an index of condition of forests. Forest crown density refers to the per cent area covered by tree crown per unit ground area. NRSA initial study has revealed significant loss of forests during 1972-83 and given alert signal to the country for conservation of forests.

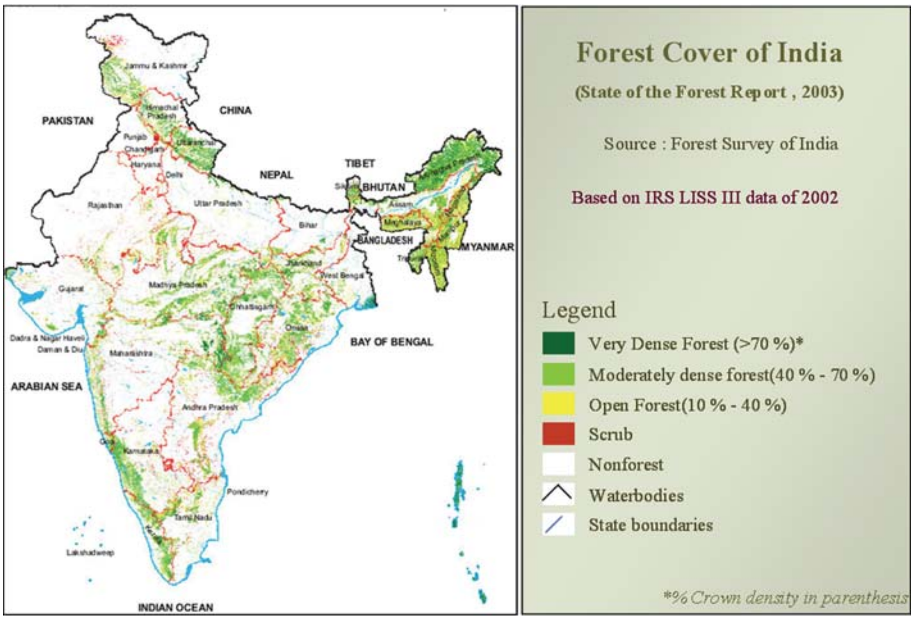


Figure 3.7: Forest cover assessment of India

In addition, the study has also established the operational methodology for national cover mapping and technology was transferred to Forest Survey of India (FSI). Since then, FSI has made ten biennial assessments. Forest cover was interpreted visually for first seven cycles at 1:250,000 scale, and then digital approaches are followed for the subsequent cycles (1:50,000) for two crown density classes 10-40% and >40%. As spatial resolution improved classes > 70 %, 40 – 70%, 10-40 % and scrub have been delineated in addition to the tree cover outside the Reserve forest areas (Figure 3.9). The present assessment (2005) represents >70 %, 40-70%, 10-40 % scrub and tree cover with multitemporal, sensor capability with total forest area reported as 67.7 Mha of the country (Figure 3.7).

3.5.3. Vegetation type mapping as potential base of bioresource

India has diverse climatic, geological, topographical and anthropogenic disturbance gradient. This has resulted in the formation of diverse vegetation communities e.g., major Eco-regions like Eastern and Western Himalayas, Shivaliks, Vindhyans, Eastern and Western Ghats and Coast constituting region specific vegetation type. Champion & Seth (1968) based on extensive ground surveys brought out forest type classification using forest structure, composition and environment (climate, topography). They identified 16 major type groups and 221 forest types. Champion & Seth (1968) classification scheme does not have spatial explicitness and with the increasing pressure on forests during the last three decades, changes at several places were noticed in forest composition. In view of this, satellite remote sensing is used as one of the effective tools to delineate forest types for better management. Forest types based on structure (canopy, height, branching, and tree density), composition (species mixture) and phenology (leaf onset/offset – leaf fall) provides unique spectral signatures. Based on the Phenological / structural properties, the 16 major type groups of the country were mapped using multi temporal SPOT and IRS WiFS data.

As part of joint initiative of Department of Space and Department of Biotechnology, 120 vegetation types covering mixed formations, gregarious formations, locale specific formations, grasslands, degradational stages, plantations, scrub and orchards were mapped for the entire country using IRS LISS-III data and available as digital database (figure 3.8). Vegetation type map for Orissa state has been shown separately in figure 3.9 depicting Sal mixed moist deciduous forest as the dominant vegetation type. This geo-database encompasses the whole

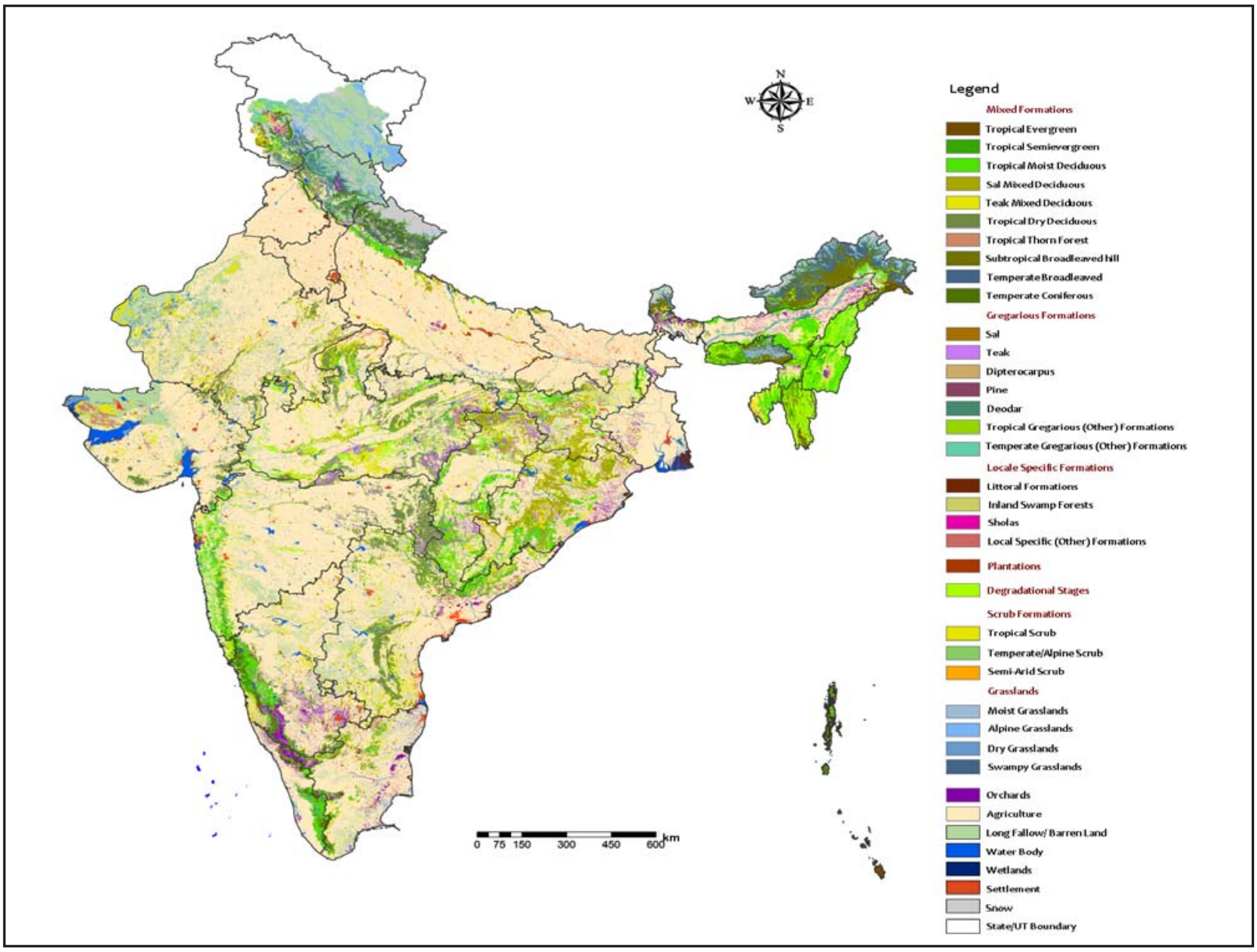


Figure 3.8: Vegetation type map of India(source: Roy et al., 2010 communicated)

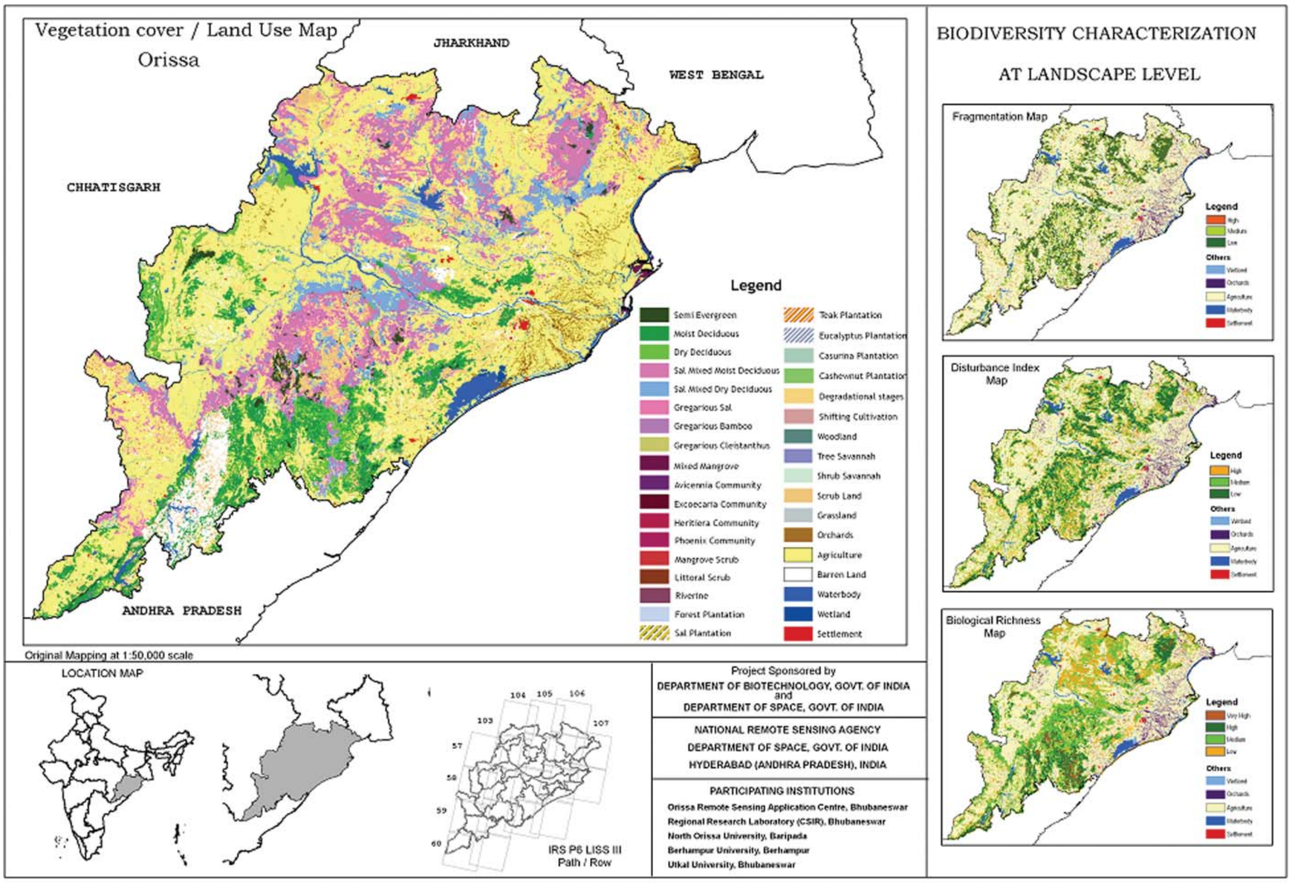


Figure 3.9: Vegetation type map of Orissa state

range of variability across climatic, edaphic and disturbance regimes across the country and also addresses the natural and man-made vegetation formations. Identification of gregarious formations (such as Red Sanders, Ephedra, Hippophae, Acacia, Sal, Teak,Dipterocarpus, Deodar etc.) along with grasslands and deciduous formations rich in medicinally important plants provide unique database for bio-prospecting prioritization. Spatial databases on locale specific formations like riverine, alpine and coastal vegetation and different degradational stages of vegetation stand as key database for conservation planning.

Currently FSI is preparing detailed forest type map for the entire country on 1:50,000 scale. These forest types have unique species composition having different economic and ecological value which can be effectively quantified using optimal ground surveys.

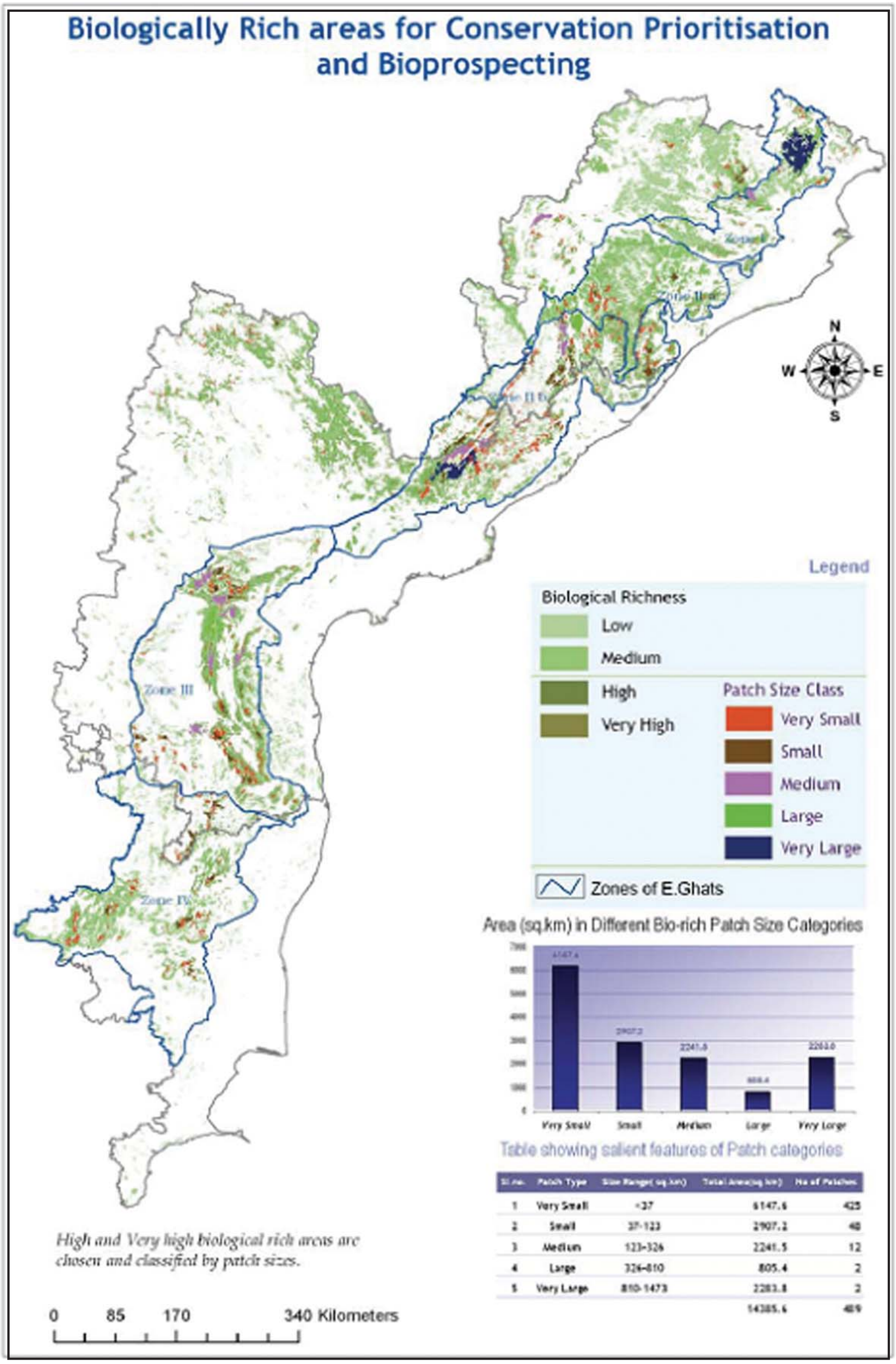


Table showing salient features of Patch categories

Sl.no.	Patch Type	Size Range(sq.km)	Total Area(sq.km)	No of Patches
1	Very Small	<37	6147.6	425
2	Small	37-123	2907.2	48
3	Medium	123-326	2241.5	12
4	Large	326-810	805.4	2
5	Very Large	810-1473	2283.8	2
			14385.6	489

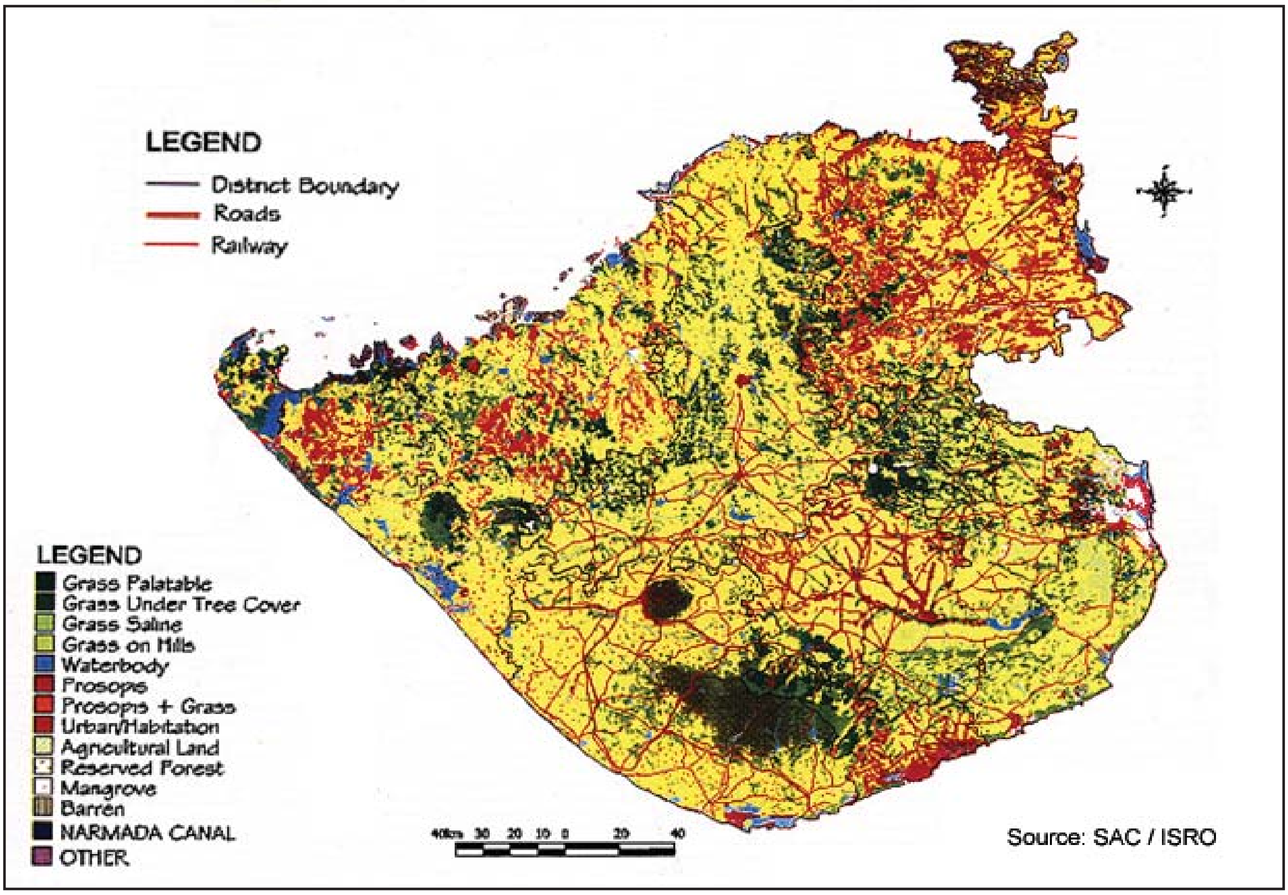
Figure 3.10: Biologically rich areas for conservation prioritization and bioprospecting in Eastern Ghats

3.5.4. Landscape level biodiversity assessment- Input for Bioresources assessment

On global to local scales, the only feasible way to monitor the Earth's surface to prioritize and assess the success of conservation efforts is through remote sensing. Currently a suite of remote sensing satellites, having various resolutions, are available to generate spatial information on vegetation and land-cover from global to local level. The remote-sensing-based information on vegetation and land cover provides a potential spatial framework and works as one of the vital input layers for the following:

- Vegetation, land cover losses and conversion
- Stratification base for optimal ground sampling and assessment of diversity
- Fragmentation and neighborhood analysis
- Delineation of broader vegetation types and analysis of species assemblages along with ancillary data
- Identification of gregarious and ecological by important species
- Inputs for species habitat models
- Spatial delineation of biologically rich zones
- Developing conservation strategies

In a major initiative, 50 Mha (80%) forests were characterized for intact and critical habitats of biodiversity under the project 'Biodiversity Characterization at Landscape Level'. The project was carried out in two phases the first phase the Western Himalayas, North East, the Andaman and Nicobar Islands and the Western Himalayas were covered. In the second phase central India, West Bengal and Eastern Ghats and East coast (Figure 3.10) was covered. The study is an outcome of the efforts of 27 Universities and 11 National institutions involving 63 scientists and 56 research scholars. Ten spatial layers comprising Vegetation types derived from remote sensing data, forest fragmentation, settlement and road buffers, ecosystem uniqueness, species diversity and economic value derived from 12,000 sample plots among others was integrated in geospatial domain to derive index of Biological Richness. The data is organized in web based 'Biodiversity Information System' facilitating query and analysis. The data provides spatial extent and relative abundance of vegetation patches of medicinal and economic value for prioritizing the plan for bioprospecting.



Source: SAC / ISRO

Figure 3.11: Grassland map of Saurashtra region of Gujarat